RONGELAP RESETTLEMENT PROJECT

Report of First Phase:

Determining Compliance with Agreed Limits

for Total Annual Dose-rate on Rongelap Island and

Actinide Contamination of Soils

on Rongelap Islands and Neighbouring Islands

by

Scientific Management Team

April 1994 (revised November 1994)

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Executive Summary

Herein is described the results of a comprehensive radiological survey of Rongelap Island to determine its compliance with agreed limits on annual dose-rate to residents subsisting on a "local food only" diet, and americium and plutonium concentrations in soil, under the terms of the Memorandum of Understanding reached between the Departments of Interior, and Energy of the United States of America and the Republic of the Marshall Islands and the Local Government of the Rongelap Atoll and signed on 21 February 1992. The present report is a non technical summary based upon seven detailed appendices carrying the detailed results of the survey.

Summary and Recommendations

Given the terms and conditions of the MoU we find that the predicted dose-rate and soil concentration of actinides are out of compliance on Rongelap Island and the neighbouring islands but that they could be met, under the terms of the MoU, by appropriate remedial action making the island safe for rehabilitation.

We recommend that:

- Urgent consideration should be given, in close consultation with the Rongelap community and their representatives, to agreeing measures to reduce the level of caesium in the local food diet and to providing, through other measures, support to eliminate the need to gather food from the more contaminated regions in the atoll.

- In the light of information being gathered on the micro-distribution of actinides in soil and on the degree to which children ingest soil, consideration should be given, again in close consultation with the Rongelap community, to measures to reduce the availability of actinides for incorporation into the body.

- In all above considerations careful attention should be paid to the need to ensure that the Rongelap community is comfortable with the safety of their islands as a future home for them and their children in perpetuity. The need to offset the loss of well-being incurred by past uncertainties concerning the radiological status of their homelands should be given a high priority when exploring with the Rongelap community solutions to redress the radiological status of their islands.

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1. Introduction

1.1 Scope and Purpose of the present report

This report is intended to be a non technical summary of the objectives, methodologies, results and implications of the first phase of the Rongelap Resettlement Project. It is backed by seven technical appendices describing in detail the methods employed and the results obtained.

1.2 Historical perspective

On 21 February 1992 a Memorandum of Understanding was reached between the Republic of the Marshall Islands Government, the Rongelap Atoll Local Government, the US Department of Energy (Office of Environment, Safety and Health) and the US Department of the Interior (Office of Territorial and International Affairs). The agreement enacted two radiological limits which must be in compliance before resettlement of Rongelap should take place. These are:

- An annual dose, over and above that from natural background radiation, of 100 mrem assuming that the diet consists of only locally produced foods, and
- A surface concentration of plutonium and other transuranic elements of 0.2 μCi/m^2 which was translated by the DoE to 17 pCi/g averaged over the top five centimetres of the soil.

The purpose of the first phase of the Rongelap Resettlement Project is to determine whether either of the limits will be exceeded on Rongelap Island and the neighbouring southern islands in the Rongelap Atoll.

1.3 Summary of the strategy employed

1.3.1 *Criteria for compliance*

The above limits are framed in the MoU in deterministic terms, i.e. that no one will exceed the 100 mrem/year compliance limit and that at no point on the island will the 17 pCi/g compliance limit for actinides in the top 5 cm of soil be exceeded. In the case of both limits determinism is inappropriate since there are no circumstances in which their being exceeded could be excluded entirely. In practice there will be a distribution of doses and activity concentrations within the population from which either a probability that an individual or location will exceed the limit, or a proportion of the population or locations exceeding the limit, can be derived.

In order to overcome this difficulty we propose to re-define the criteria for the limits being exceeded in probabilistic terms as follows:

- The limit will be deemed exceeded if 1% or more of the population or locations exceed the compliance limits, or an individual or location has a 1% or more chance of exceeding the compliance limits.

The 100 mrem/year limit is taken to include all sources of exposure other than natural background radiation, i.e. external radiation from nuclides in the terrestrial environment and internal radiation derived from locally produced foods. In practice the dominant contributor to both will be caesium-137 (^{137}Cs) in the soil and transferred to the food chain. Other nuclides, e.g. americium-241 (^{241}Am) and cobalt-60 (^{60}Co) contribute to external exposure and strontium-90 (^{90}Sr) contributes to internal exposure. In the following dose rates from ^{137}Cs have been calculated and the additional contribution from other sources estimated.

1.3.2 *Determining compliance*

Natural background radiation from external sources is low in coral atolls due to the lack of minerals in the terrestrial environment. Never-the-less, direct measurement of external exposure with, for example, an ionisation counter, would entail subtracting a component for natural background. Direct measurement of ^{137}Cs allows the direct determination of exposure from fallout.

The following integrated strategy has been adopted;

- *in situ* measurements of the gamma spectrum one metre above the ground and at 200 m intervals over Rongelap Island have been made with a germanium detector and count rates for ^{137}Cs and ^{60}Co determined from the spectra.
- Four grid squares were selected, two in the vicinity of the main settlement (where soil disturbance was likely) and two remote from it, and within each 25 further measurements were made.
- Determinations of the distribution of ^{137}Cs with depth in the soil have been made at 12 of the 63 locations measured.
- ^{137}Cs, ^{60}Co, ^{241}Am and plutonium-239,240 ($^{239,240}Pu$) have been determined from a composite of three 15 by 15 by 5 cm deep samples taken within 15 m of each *in situ* measurement.
- ^{137}Cs has been measured in samples of foodstuffs at a relatively small number of locations primarily to confirm the much more comprehensive measurements of food samples by DoE. Intercomparisons have justified the use of those data.
- Maps of ^{137}Cs count rates (S(x)) and total Pu and Am concentrations in soil have been prepared by interpolation from the sample points.
- By application of the "radii of utilisation" maps of Cs count rate in soil averaged over radii of 200, 500 and 1000 m ($T_R(x)$) have been derived.
- ^{137}Cs count rates have been converted, with the help of the soil profile data, to ^{137}Cs concentrations in soil and compared with the soil determinations.
- Plant:soil transfer factors have been derived from measured concentrations in vegetation and soil and supplemented by earlier data collected by the DoE and the distribution of values computed.
- Doses from external exposure have been derived from the ^{137}Cs in soil values and measurements of ^{60}Co and ^{241}Am for a series of "radii of utilisation" and conditions of living (i.e. time out of doors, on lagoon etc.).

- A survey of the diet of the residents of Mejatto has been carried out and the distribution of caloric intakes and the contributions from local and imported foods determined. (Since 1985 Mejatto Island on Kwajalein Atoll has served as the home of the relocated Rongelap community).
- Following consultation with the Rongelap communities in Mejatto. Majuro and Ebeye, the local food only diet to be used in dose assessment has been agreed.
- Doses from internal exposure have been derived from the local food only diet and based on the measured energy intake distribution for the Mejatto community and the derived soil transfer factors for ^{137}Cs.
- Estimates of internal exposure to other nuclides (about 2% of total internal dose) are based on earlier measurements by the DoE.
- Concentrations of plutonium in bone tissue were measured in deceased residents of Rongelap.
- Historic whole body counting data for Rongelap residents between 1958 and 1985 were analysed.
- No account has been taken of doses from inhalation or from the drinking of well water where the contributions to total dose rate are expected to be very tiny.

Initial measurements of ^{137}Cs count rates showed significant variation of ^{137}Cs in soil across the island which may indicate either differences in the retention of Cs in the soil, perhaps due to variations in the organic components of the soil or disturbance (leading to burial) of the Cs in the soil. Given such variations, doses will depend to some degree on patterns of behaviour of the inhabitants. To incorporate this aspect we have employed the "radius of utilisation", R, calculating doses for values ranging from 100 m to 1 km. Surveys of behaviour by interview with the community on Mejatto and through observation and interview on an outer island have been made in order to justify the choice of "R".

It is to be noted that although the internal and external components of the dose are separately computed, the total dose is not the linear sum of the two since both depend on soil concentration and are also a function of body mass.

1.3.3 *Rationale for constructing ^{137}Cs count rate and actinide concentration maps*

Measurements made at discrete locations either by soil sampling or gamma spectroscopy are subject to two kinds of error, namely the measurement error and the error due to having sampled only a small area, a few hundreds of square cm in the case of a soil sample and about 100 square metres in the case of gamma spectroscopy. The mapping process interpolates between sampling points to derive a smooth surface, using adjacent points on the sampling grid to help reduce the sampling error term. As such this process "averages" to some degree and so narrows the distribution of concentrations when compared to the distribution of measured values. This process has the effect of improving confidence in the extreme ends of the distribution of count rates.

2. Methodology

2.1 Measurements of external exposure (see Appendix A3)

Hyperpure germanium detectors were used for all spectrometric measurements both *in situ* and in samples taken of soils and vegetation for laboratory analysis .

All *in situ* measurements were made according to the method of Beck et al. (1972)[1] and interpreted by their methods as well as by those described by Jacob and Paretzke (1986)[2]. Laboratory detectors were calibrated by standard procedures and verified by a five laboratory international intercomparison study.

In situ measurements were made at 63 locations on a 200 m grid over the island (see figure 2.1) and at 100 locations within four 200 m grid squares at 40m spacing. These values were used to construct maps of count rate, S(x), by interpolation between points on the grid matrix and maps of count rate averaged over various radii. $T_R(x)$ (see Appendix A3).

Count rate in the full energy peak is dependent on the vertical profile of activity in the soil due to scattering of photons from deeply buried activity. Soil profiles to a depth of 30 cm (6 increments by 5 cm depth each) were taken in order to correct for this effect.

Three soil samples were taken within 15 m of the sites of each *in situ* measurement, packed, dried and counted under standardised conditions in the laboratory.

^{60}Co and ^{241}Am also make a contribution to external dose and measurements of the count rates in the ^{60}Co and ^{241}Am full energy peaks were also made .

Conversion factors for corrected count rate to exposure rate were taken from Beck (1972) and for exposure rate to dose rate from ICRP Publication 51[3].

2.2 Measurement of internal exposure

Levels of caesium contamination of vegetation depend on the soil concentration of Cs and to a lesser extent, the plant species. The ratio plant:soil for ^{137}Cs has been determined for a number of local food types, the most important of which is the coconut. Although there is considerable variability from sample to sample a value of 0.2 for both the liquid and solid components of the drinking coconut is representative with 50% of all samples within a factor two above and below. Calculation 2 uses probability distributions using data from this and other studies. The data acquired in this study have been supplemented by earlier data collected on Rongelap by DoE.

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[1]Beck, H. L., DeCampo, J. and Gogolak, C. 1972 In situ Ge(Li) and NaI(tl) Gamma-ray Spectrometry. HASL-258 Health and Safety Laboratory, US Atomic Energy Commission.
[2]Jacob, P. and Paretzke, H. G. 1986 Gamma-ray exposure from contaminated soil. Nuclear Science and Engineering, 93, 248-261.
[3]ICRP Publication 51, 1989 Data For The Use In Protection Against External Radiation Annals of the ICRP, 20 (2).

The dietary survey yielded a distribution of energy intakes for the Mejatto population which was corrected as described in the section on the Dietary Survey to reduce the overdispersion due to the use of single 24 hour recall data set. Body mass and height data were recorded in the dietary survey. Basal metabolic rates were estimated from the relationship of Schofield et al.[4]

2.3 Diet survey (see Appendices A4)

For more than 100 years, the Marshallese diet has consisted of a mixture of imported and local foods. From the periods of the occupations by Germany in the mid-1800s, the Japanese, and finally the Americans, the Marshallese people have subsisted on varying types and quantities of imported food as an adjunct to their abundant but monotonous marine-based diet. As atoll dwellers [and not agriculturists] the Marshallese and other people living in Pacific atolls have the most restricted diet of all oceanic peoples.

A local food only diet cannot be measured directly since there appears to be no population in the Marshall Islands which subsists for prolonged periods of time on a diet consisting of entirely local food items with no consumption of imported foods. Even if one were to conduct a dietary survey on more traditional islands, the problem would remain how to substitute imported food items, such as instant noodles or rice, with local food items.

The dietary survey was designed to satisfy two requirements of the dose calculation, namely to provide a distribution of energy intakes and to indicate the nature of the local food in the current diet on Mejatto.

A 24-hour recall survey was chosen to give an estimate of the mean intake of nutrients and energy. Given the small size of the Mejatto population and the desirability of including everyone in the survey, a single 24-hour recall was collected from all Mejatto residents. Heights and weights of the population were taken as an external validity check of the mean energy intakes. A repeat survey of women 18 years and older was conducted.

Training was given to twelve volunteers of the Mejatto community during a five day workshop in Majuro. The training program ensured that the interviewers understood the objectives of the dietary survey; had a rounding in basic nutrition relevant to the Marshall Islands' food culture; developed skills in interviewing techniques; were able to use common food utensils and food models to elicit amounts of food eaten by interviewees; were able to fill-in the dietary questionnaire; and understood the importance of the dietary survey in relation to the Rongelap Resettlement Project as a whole. A detailed description of the diet survey questionnaire, the use of utensils, food models and measures, the recipes and the process of data collection can be found in Appendix A4.

Dietary data was collected from 319 residents, with a repeat 24 hour recall of 48 women 18 years and over, several days after the first recall. The survey was planned so that interviews were spread evenly over the different days of the week, and so that interviewers carried out their

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[4]Schofield, W. N., Schofield, C. and James, W. P. T., 1985 Basal metabolic rate - review and prediction, together with an anotated bibliography of source material. Human Nutrition: Clinical Nutrition 39C(Suppl 1) 1 - 96.

interviews in at least two households each day, and attempted to interview a mixture of men, women and children each day. The age and sex distribution of those interviewed is shown in Table 1.

Table 2.1 Description of population and measurements obtained

Age-sex grouping	Weight data	Height data	Diet data	Repeat diet data
Males				
< 5 yr	20	14	30	-
5 - 9 yr	28	28	33	-
10 - 17 yr	36	35	42	-
18 - 60 yr	51	51	62	-
>60 yr	3	3	6	-
Females				
< 5 yr	17	12	26	-
5 - 9 yr	26	26	30	-
10 - 17 yr	22	22	26	-
18 - 60 yr	48	54	54	42
>60 yr	8	10	10	6

The data from the survey were analyzed using the Nutritionist IV version 2.0 database. For nutrient information on local foods such as coconuts, the 1983 South Pacific Commission tables were used.

The data for mean energy intake (EI) as well as consumption of protein, carbohydrates and fat are commensurate with reference data (ICRP Publication 23). The average protein intakes of men and women are higher than the US Recommended Dietary Intakes whereas the energy intakes are slightly lower. Intake rates for males are higher than for females.

Table 2.2 provides an analysis of the observed energy intake rates in comparison with the estimated basal metabolic rate. The observed mean energy intake for men and women of 1.6 times the estimated mean basal metabolic requirement (BMR_{est}) is consistent with sedentary-light activity. The distribution is over-disperse with a small number of individuals reporting energy intakes below their estimated basal metabolic rate, whereas the maximum reported energy intake would be equivalent to unrealistically high physical activity levels.

Since annual mean values for energy intake are needed for the dose assessment, the variation in intake is described by a lognormal distribution of the ratio of EI/BMR_{est} whereby the standard deviations of the natural logarithm of the mean m is adjusted such that the 1st percentile of the distribution is equivalent with a ratio of $EI/BMR_{est} = 1$. Since very heavy physical activity is associated with an average daily energy intake of 2.3 EI/BMR_{est} for males and 2.0 for females, the 99th percentile reflects reasonable upper limits of EI/BMR_{est}.

Table 2.2 Energy Intake (EI) compared to the estimated basal metabolic rate (BMRest)

Parameter	Boys 10-17 yr (N=35)	Girls 10-17 yr (N=22)	Men 18+yr (N=53)	Women 18+yr (N=41)
observed data:				
EI/BMR_{est}, avg	1.6	1.7	1.7	1.4
EI/BMR_{est}, min	0.46	0.69	0.59	0.72
EI/BMR_{est}, max	2.4	2.5	3.5	2.3
m (EI/BMR_{est})	0.41	0.51	0.45	0.33
s (EI/BMR_{est})	0.33	0.32	0.39	0.28
adjusted data:				
m (EI/BMR_{est})	0.41	0.51	0.45	0.33
s (EI/BMR_{est})	0.18	0.22	0.19	0.14
EI/BMR_{est}, 01-percentile	1.0	1.0	1.0	1.0
EI/BMR_{est}, 50-percentile	1.5	1.7	1.6	1.4
EI/BMR_{est}, 95-percentile	2.1	2.6	2.3	1.8
EI/BMR_{est}, 99-percentile	2.3	2.8	2.4	1.9

A local food only diet was derived using the following principles:

- Energy intake derived from measured energy intakes of the Mejatto community.
- Items available on Rongelap and providing a good balance of nutrients.
- The selection of food items not be biased by availability or non-availability of radionuclide data on the food item.
- Diet determined in consultation with local community.

With the endorsement by the Rongelap communities, the following diets were selected:

(#1) "Mejatto observed"
The current level of local food items as observed in the Mejatto survey (about 18% of total energy intake)

(#2) "Mejatto scaled"
Imported food items are replaced by local food items on a calorie-by-calorie basis in

in the same proportions as these local food items were consumed in the mean on the same proportions as these local food items were consumed in the mean on Mejatto during the survey.

(#3) "Mejatto scaled with rice"
same as #2 but accounting for the same mean rice consumption as observed on Mejatto (between 25% and 30% of total energy intake).

(#4) "Naidu et al., scaled"
Imported food items are replaced by local food items on a calorie-by-calorie basis in the same mean proportions as these local food items were reported in the Naidu et al. survey.[5]

(#5) "Naidu et al., scaled with rice"
same as #4 but accounting for the same mean rice consumption as observed on Mejatto (between 25% and 30% of total energy intake).

Table 2.3 provides a nutritional analysis of the selected diets.

In addition, calculations of local food consumption in between the intake observed on Mejatto and a 100% level were requested by the communities. However, the Diet #2 ("Mejatto scaled") was endorsed as the basis for the dose assessment.

2.4 Determination of actinides in soil (see Appendix A6)

Concentrations of ^{239}Pu and ^{240}Pu and ^{241}Am were determined in pooled samples (15 by 15 cm by 5 cm deep) taken at three points within 15 m of the site of each of the *in situ* spectroscopic measurements. Americium concentration was determined by laboratory gamma spectroscopy measurements of the 59.5 keV emission. Plutonium was determined radiochemically using microprecipitation onto a neodymium fluoride substrate followed by alpha counting with passively implanted silicon detectors. This technique was verified by interlaboratory comparisons with laboratories in New Zealand, Germany and the USA.

Interpolation maps similar to those prepared for the ^{137}Cs were prepared for actinides.

Calculation of total dose from ^{137}Cs (see Appendix A5)

This calculation has been carried out in duplicate at two separate locations (Majuro, RMI and Sussex, UK) with entirely independent programming and according to the same protocol as described in detail in Appendix 4 but with some small differences in approach. This was done to ensure that the final result contained no artifacts of programming or misinterpretations of the primary data.

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[5] Naidu, J.R., et al. Marshall Islands: A study of diet and living patterns. Brookhaven National Laboratory, Upton, N.Y. July 1980, BNL 51313

Table 2.3 Key data for diet models to be used in Rongelap compliance assessment (data for females >18 yr; *data for males >18 yr*)

Diet Parameter	#1 Mejatto	#2 Mejatto scaled w/o rice	#3 Mejatto scaled with rice	#4 Naidu et al. scaled w/o rice	#5 Naidu et al. scaled with rice
Total Energy Intake	1,900	1,900	1,900	1,900	1,900
(kcal/d)	*2,750*	*2,750*	*2,750*	*2,750*	*2,750*
Energy Intake from	18%	100%	75%	100%	75%
Local Foodstuffs	*17%*	*100%*	*70%*	*100%*	*70%*
(Percent)					
Energy Intake from Rice	25%	0%	25%	0%	25%
(Percent)	*30%*	*0%*	*30%*	*0%*	*30%*
Protein Intake (g/d)	72	82	71	100	87
	110	*130*	*110*	*150*	*120*
Carbohydrate Intake (g/d)	260	140	210	180	240
	360	*130*	*260*	*260*	*360*
Fat Intake (g/d)	67	120	92	80	61
	95	*200*	*130*	*120*	*83*

Dose from ^{137}Cs arises from two sources, namely external, from the radionuclide in the soil, and internal, from the nuclide transferred from the soil to the food chain either directly from the consumption of leaves, vegetables and fruit or indirectly from locally grown animals such as pigs, chickens and coconut crabs. Both components depend upon the concentrations of ^{137}Cs in soil. Soil concentration can be inferred from measurements of the count rate of ^{137}Cs as measured with a high resolution gamma spectrometer *in situ* under standard conditions (height above the ground etc.) when allowance has been made for the burial of the Cs in the soil. Burial has the effect of scattering radiation thus reducing the contribution to count rate in the unattenuated energy band or full energy peak for the nuclide.

The external component of dose rate depends on the extent to which an individual moves around the island, particularly if the count rate varies markedly from one part of the island to another. A relatively immobile individual will have an exposure rate typical of the locality in which he or she spends most time whereas a mobile individual will approximate to the average exposure rate for the island. This "mobility" factor is allowed for in the "radius of utilisation" and is used in the mapping procedure to convert the S(x) maps to $T_R(x)$ maps. Because the construction of the S(x) map involves interpolation between points on the 200m grid. the dispersion of values of S(x) over the island is narrower than that for the original measurements (the interpolation is in effect an averaging process over the order of distance equal to the grid spacing) and averaging over greater distances to construct $T_R(x)$ maps further narrows the distribution towards the average. Calculation 1 uses the S(x) and $T_R(x)$ maps (for R=500) whereas calculation 2 is based upon the measurements without interpolation or averaging.

The internal component depends upon diet and the extent to which it includes contaminated local foods. Caesium transfer is not highly selective and uptake from the soil depends on factors such as the depth distribution of the Caesium in the soil in ways that are not fully understood. The ratio between Cs in vegetation and soil is termed the plant:soil transfer factor. Calculation 1 uses a single value of 0.2 and applies a sensitivity analysis in order assess the dependence of total dose on this factor which lies in the range 0.1 to 0.4. Calculation 2 uses probability distributions using data from this and other studies. In both cases the soil concentration is the reference for calculating exposure so food gathered in a particular locality will reflect the caesium activity in the soil at that location.

Both the external and internal dose rates depend on body mass. In the external case dose rate is derived from exposure rate using standard ICRP conversion factors[6]. For internal exposure dose rate will depend upon energy intake, diet, and body mass. A diet survey of the inhabitants of Mejatto was used to assess the contribution of local foods to the present diet and to assess the distribution of energy intakes. The fractions of time spent in different activities was based on previous DoE assumptions

Dose was calculated according to the protocol given in Appendix A2. There are a number of ways of carrying out this calculation. In selecting the method used we were mindful of the need to use a method that was readily comprehensible as well as reliable. The approach has been to calculate only the contribution from ^{137}Cs, using sensitivity analyses to determine whether or not the calculation is "robust" to reasonable uncertainties of fluctuations in values. Dose rate distributions have been computed for men and women separately (i.e., for the community of men or women, not for individuals). Dose to children was dealt with by comparison of energy intakes in relation to body masses. Dose distributions were derived using a Monte Carlo technique, drawing at random from the distributions of soil concentration, body mass and energy intake and in calculation #2, plant:soil concentration ratios as well. Reference is then made to the assumed diets, #1 representing the measured Mejatto diet, #2 the "local foods only diet" agreed with the Rongelap community and 3 other derived diets.

[6]ICRP Publication 51 Data For The Use In Protection Against External Radiation Annals of the ICRP, 20 (2), 1989.

4. Results

4.1 Total Dose Rate

Results are calculated as cumulative dose rate distributions under differing sets of assumptions. For simplicity they are presented herein as tables giving the annual dose rate for various percentiles (from 5th to 95th).

The results of calculations are given in tables 4.1 and 4.2 for men and women respectively. Calculation 1 is based on the $T_{500}(x)$ map and a single value of the plant:soil concentration ratio (= 0.2). Calculation 2 is based on the distribution of measured values of ^{137}Cs count rate and uses probability distributions for the plant:soil transfer factors for different plants. As anticipated the dispersion of the distribution based on $T_{500}(x)$ (calculation 1) is narrower than calculation 2 due to the greater degree of spatial averaging involved. Conversely, calculation 2 is broader due to the greater dispersion of the measured values and has a higher mean value due to the use of individual values for the plant:soil ratio which are generally higher than the "base value" of 0.2 used in calculation 1.

Table 4.1 Dose rates[7] (mrem/year) for men over the age of 18

Percentile	Calculation 1			Calculation 2		
	Diet #1	Diet #2	Diet #3	Diet #1	Diet #2	Diet #3
5	17.5	59.5	44.5	8.9	40.2	32.1
25	20.5	72.5	54.5	20.3	85.7	67.2
50	22.5	85.5	63.5	28.4	124.8	94.5
75	25.5	101.5	74.5	36.7	168.4	121.5
95	30.5	130.5	95.5	52.5	280.6	173.8

Table 4.2 Dose rates[8] (mrem/year) for women over the age of 18

Percentile	Calculation 1			Calculation 2		
	Diet #1	Diet #2	Diet #3	Diet #1	Diet #2	Diet #3
5	17.5	54.5	43.5	8.6	36.2	30.3
25	20.5	67.5	53.5	19.2	76.2	61.1
50	22.5	78.5	61.5	28.2	108.0	86.8
75	25.5	91.5	71.5	36.2	149.6	101.2
95	29.5	114.5	88.5	49.8	216.1	152.5

[7] Developments in geostatistical modelling presently in progress will lead to changes in the results of calculation 1. In general the distribution for S(x) will be broadened and shifted to somewhat higher values. Spatial averaging of the results of calculation 2 may lead to a narrowing of the distribution.

[8] see note 7

4.2 Dose from other radionuclides

External exposure due to ^{60}Co and ^{241}Am will increase the external component by about 1%. Strontium-90 may add a further 2% to the internal dose. Actinides, due to their very limited uptake into the plants, contribute a few percent to internal dose.

4.3 Dose to Children

The smaller body mass of children potentially exposes them to greater doses than adults. It can be demonstrated that although the dose per unit intake is higher for children than adults by a factor 1.4 to 1.5 for the 6 to 10 year old, the energy intake more than compensates, such that under identical exposure conditions the ^{137}Cs doses to small children are typically 54% of those to adult males and 74% of the adult female values.

For young children the intake of actinides from direct ingestion of soil has yet to be examined but is unlikely to add much to the dose. It should, however, be examined as an issue in its own right.

4.4 Actinide concentrations in soil

On Rongelap Island 1.1% (2/175) of the measured values for Am and Pu exceed the compliance limit of 17 pCi/g. The interpolation map was not used in the context of compliance since the requirement is to ensure that there are no points with measured values above the limit. The map does, however, help to locate those regions of the island that have consistently high values. For neighbouring islands, measurements indicate 14% (6/43) of measurements fail to comply with the limit.

5. Discussion

5.1 Total annual dose rate

The results indicate that, on the basis of ^{137}Cs exposure alone, between 25 and 75% of male members of the Rongelap community would exceed the compliance limit of 100 mrem/year while living a traditional outer island lifestyle and consuming a local food only diet. The internal dose dominates. The additional contribution from ^{60}Co and ^{241}Am to external exposure is small, perhaps of the order of 1% of that from ^{137}Cs. Strontium-90 contributes to internal exposure and may be expected to increase the internal component of dose by 2%. It is noted that calculation 2 yields somewhat higher doses and has a wider dispersion of values. This is because of the higher plant:soil ratios used and the fact that the underlying distributions are lognormal. Estimates of radiation doses made from whole body counting data of former residents of Rongelap Atoll during the years 1958 to 1985 indicate that if the same diet and food collection patterns applied now, as then, with a mixture of local and imported foods, a small fraction of the population would be above the 100 mrem/year compliance limit.

It should be noted that all calculations are based on the local food being gathered from Rongelap Island. The traditional food gathering islands lie in the north of the atoll and are more, and in some cases considerably more, contaminated than Rongelap Island. The effect of gathering food from these islands would be much the same as increasing the value of the plant:soil ratio. We consider it unreasonable to assume that in practice the gathering of food from these islands, particularly in times of water and food shortages, can be effectively prohibited.

As stated earlier. attention has been concentrated on ^{137}Cs because of its dominance and because it is possible to reduce exposures by practical measures. There is for example considerable scope for reduction of the internal component by treating growing areas with potash fertilizer[9]. A reduction by a factor four, which can be achieved by this technique, will more than halve the total dose values bringing almost all the population within the 100 mrem/year compliance limit on the basis of a local food only diet. The consumption of imported foods will reduce doses further.

However, we believe more extensive measures than potash fertilisation are called for. The 100 mrem/year (1mSv/year) limit is widely[10] regarded as the limit of acceptability for public exposure to ionising radiation, for practices which give rise to exposures in addition to those arising from natural and medical exposures, although it is generally accepted in radiological circles that the health impact of such exposures is small. Public concern for health detriment, real or imagined, is in itself a health detriment when health is viewed in its widest sense, that is, including loss of well-being as a detriment. Thus measures which reduce the likelihood that community members would exceed the compliance limit would serve to minimise the detriment caused by concern for their health.

In the case of the Rongelap community the most likely contributing factor to increasing dose will be the need to visit the northern islands at times of food and water shortages. Measures to ensure adequate water and food supplies on Rongelap Island, such as ground or ocean water purification and the capability to refrigerate and store protein foods, are examples of measures that contribute in that direction. We recommend that careful consideration is given to this type of mitigation in close consultation with the Rongelap community.

5.2 Actinide contamination of soil

While the failure to comply with the limit on Rongelap Island is marginal it has to be acknowledged that there is more concern worldwide about exposure to actinides than other forms of radioactivity. Given that many of the measured values are close to the limit we believe it worthwhile to take some remedial measures, especially to reduce the possibility of intakes by young children ingesting contaminated soil. Measurements are in progress to determine the micro-distribution of the actinides which will assist in determining the best strategies for remedial action but we have in mind the provision of, for example, radiologically clean coral to provide actinide free surfaces around houses and in community areas. The study of plutonium in

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[9]Robison. W. L. and Stone. E.L. 1992, The effect of potassium on the uptake of ^{137}Cs in food crops grown on coral coils: coconut at Bikini Atoll. Health Physics 62, 496-511.

[10] 1mSv/year is the ICRP recommended public dose limit for planned exposures when averaged over a lifetime. It should be noted that implicit in this figure is the assumption that societal benefit is derived from the activities that lead to this exposure. In the case of the exposures from living on Rongelap the exposed community derives no benefits.

bone from exhumed Rongelap residents does not indicate that the actinides are readily transferred to man, even as children. On the basis of these measurements the contribution to the 100 mrem/year limit is about 1%.

The compliance limits are clearly exceeded on the neighbouring islands and attention will have to be given to remedial measures appropriate to the use to which these islands will be put.

6. Summary and Recommendations

Given the terms and conditions of the MoU we find that the predicted dose-rate and soil concentration of actinides are out of compliance on Rongelap Island and the neighbouring islands but that they could be met, under the terms of the MoU, by appropriate remedial action making the island safe for resettlement.

We recommend that:

- Urgent consideration should be given, in close consultation with the Rongelap community and their representatives, to agreeing measures to reduce the level of Caesium in the local food diet and to providing, through other measures, support to eliminate the need to gather food from the more contaminated regions in the atoll.

- In the light of information being gathered on the micro-distribution of actinides in soil and on the degree to which children ingest soil, consideration should be given, again in close consultation with the Rongelap community, to measures to reduce the availability of actinides for incorporation into the body.
- In all above considerations careful attention should be paid to the need to ensure that the Rongelap community is comfortable with the safety of their islands as a future home for them and their children in perpetuity. The need to offset the loss of well-being incurred by past uncertainties concerning the radiological status of their homelands should be given a high priority when exploring with the Rongelap community solutions to redress the radiological status of their islands.